Astronomical History  The Hubble telescope has been a major tool for the last fifteen years. However, astronomy is as old as man – the earliest known good star map was by Hipparchus 2500 years ago, and a Roman statue (now in Naples) is of Atlas supporting a celestial globe. In 1610 Galileo made the first telescope, opening up the sky; he was able to see the moons of Jupiter, which clearly orbited Jupiter – not Earth, then considered the absolute centre of the universe… Larger telescopes were soon built, with long tubes to accommodate the low curvature lenses that gave the best results – they were not easily manoeuvred. There is a large 28" Refractor at the Observatory in Greenwich, designated ROG, made in 1893 but on an 1859 mount, which even in London’s atmosphere is useful for planetary observation. In 19thC astronomers began to study not just the location of celestial objects but what types they were.

Reflecting Telescopes  These use a mirror as the prime element to gather and focus light. Small ones were made in the late 18thC, then in the early 19thC Herschel designed one with an 18" mirror. Mirrors being supported from behind, are easier to mount than lenses can only be held at the edge; they can gather more light and give a brighter, sharper image.

In 1948 the 200" (5 m) Hale telescope at Mount Palomar set a new standard, high up above much of the atmosphere for maximum clarity. This was built for traditional observation by eye; then longer exposures were made possible with photographic plates; now CCDs (Charge Coupled Detectors) give higher sensitivity. Telescopes have to be at atmospheric temperature to prevent thermal distortion of their structure, so the observer, or photographer changing the film, could have to put up with -20°C temperatures - the CCD means that the observer is no longer tied to the instrument. In order to be able to focus on an object in the sky as the Earth rotates telescopes usually have a mount parallel to the Earth’s axis; the framework of the mount has to be sufficiently rigid (or have strain adjustment) to hold the lens/mirror at the desired amount of tilt.

Hubble Telescope  This has a 2.5 m mirror, smooth to 1/50 wavelength, sensitive from ultra-violet to near infra-red, giving resolution to 0.05" of arc, and can see objects down to magnitude 31 (magnitude 6 is visible to the eye on earth). It is ten times more effective in space than on earth. It was launched into a low earth orbit and maintained by the Shuttle, including a refit at three years to properly focus the mirror. It is due for another maintenance mission but is unlikely to get it, so it may not last more than a couple of years before it is put into an orbit that will burn it up.

Successes  The main discoveries from its use are: the Hubble Deep and Hubble Ultra-Deep Fields; determining the age of the universe as 13.7 billion years; seeing planetary systems being formed; observing the surface of Pluto.

Within the solar system Hubble pictures of planets are often as good as from visiting probes. It followed a transit of Io across Jupiter, and has been used on its other moons. Greater detail has been seen on other planets – Uranus, at 2000 Gm, has ring system showing weather movements. Further out objects have been studied.

Star studies of a nebula in the Orion constellation have shown young stars and a planetary system. Brown dwarfs, Gliese (between planet and star size) first seen in 1990s, are now known to be numerous. Two giant objects are likely to have a supernova explosion soon – Betelgeuse with an atmosphere bigger than Jupiter’s orbit, which could affect Earth, and the Eta Carini black hole (the last supernova in our galaxy was six years before the invention of the telescope, there was a nearby
one in 1987). The Sun will eventually become a white dwarf, larger stars go to neutron stars (a teaspoonful of which would weigh 14 Mtonne); beyond that Black Holes are formed, Hubble results confirming their existence. There is a large one at the centre of our galaxy and about 10 000 others near it, with stars moving very fast – it is now believed that this is necessary to hold the galaxy together. In 1960s satellites put up to monitor the Test Ban treaty recorded gamma-ray bursts; these have been found to come from beams emitted by Black Holes in distant galaxies (formed before the Sun) – if from nearer, such beams would fry the Earth. Einstein predicted gravitational lenses, and their effects were seen as distorted galaxies in the Hubble Deep Field using a $10^5$ sec (> 1 day) exposure in a dark patch in the Plough. In 2004 the Hubble Ultra-Deep Field a was studied over $10^6$ sec (> 2 week). The Universe is bigger now, and newer stars differ in having more chemical elements, created as older stars were destroyed and the material recycled.

**New Telescopes** There is one with an 8 m mirror on a high mountain peak in Chile, where it is very dry. Designs for future land based telescopes, using adaptive optics (the acronym is NACO) to counteract atmospheric turbulence, will give comparable sensitivity to the Hubble telescope. Lighter mirrors can be made, now up to 10 m; a Very Large Telescope (VLT) with a 100 m mirror is proposed by Europe for 2020, called OWL, at a similar cost to Hubble.

Space telescopes have the advantage of being outside the Earth’s atmosphere and can work in the UV. The International Space Station has some small telescopes, including one for X-rays. There is a European 10 year plan for a ‘Darwin’ system of several small telescopes.

**Interferometry**, using two linked telescopes, could give an effective aperture equal to their distance apart – though combining their inputs would be extremely difficult at optical wavelengths and need a clock of $10^{15}$ Hz (interferometry with much longer wavelength Radio telescopes is easy and is done across the world). VLTI (VLT + Interferometry) would give the ability to see Earth size planets orbiting other stars; or a person on the moon.

**Economic Benefit** In answer to a question on the value of deep space astronomy, Dr Massey said there were two main benefits to the world at large: the technological spin-off, such as the development of CCDs which are now ubiquitous in cameras and even mobile phones; and more importantly in his view, the attraction of new blood to the Engineering profession.